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955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 07014

SUBJECT: Tektite II - Aeromicrobiology Experiment and the Environmental Control System
Case 105-5

DATE: June 30, 1970

FROM: L. D. Sortland

NASW-417

ABSTRACT

Objectives and procedures for the Tektite II aeromicrobiology experiment have been reviewed. It is observed that interpretation of the experiment data may be influenced by the air mixing patterns present in the Habitat. Results of a General Electric test of the air distribution system suggest that the mixing is much greater than the theoretical prediction. An experimental program is proposed to resolve this discrepancy.

In a further study of the environmental control system, motivated by the near abort condition which occurred on the PX-15 Gulf Stream Drift Mission, the potential for carbon monoxide buildup in the Tektite II atmosphere was analyzed. The literature dealing with CO generation rates by man, and with the effect on man of long term CO exposure, was reviewed. It was concluded that:

1. Steady state will be approached within ten days. Carbon monoxide levels will probably exceed the National Academy of Sciences recommendation for long term exposure by a factor between one and two.

2. Since the NAS recommendations are quite conservative, no appreciable physiological effect should be evident in healthy individuals at the anticipated maximum levels of 30 ppm, although a small decrement in mental performance may occur. This decrement will probably not be observed in the absence of sensitive measuring techniques.

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MEMORANDUM FOR FILE

INTRODUCTION

On February 17, the author went to General Electric, Philadelphia, with Dr. Andre Cobet, Principal Investigator for the Aeromicrobiology Study on Tektite II. The purpose of the meeting was to review the Environmental Control and Air Distribution System (ECADS) for the Habitat, and to make a tentative decision as to the air sampling locations.

Following a briefing on the ECADS, an inspection of the Habitat, located at the Naval Shipyards, was made. During the briefing, we noted that the air distribution systems in the two cylindrical tanks making up the Habitat were essentially isolated from each other. General Electric had performed a test of the ECADS[1] in which CO_2 was released in one tank and removed in the other, and the results indicate that good inter-tank mixing was achieved. However, these results appeared to be inconsistent with the predicted amount of mixing possible via the air distribution system. Since the interpretation of the aeromicrobiology experiment may be influenced by the mixing patterns present in the Habitat, the author performed an analysis of the ECADS in order to evaluate the GE test.

Motivated by the near abort condition which occurred on the PX-15 Gulf Stream Drift Mission, a study of the potential buildup of carbon monoxide in the Tektite II atmosphere was also performed.

The Tektite II Environmental Control and Air Distribution System

Figure I is a schematic diagram of the Tektite II Habitat and the ECADS. Primary control of CO_2 is achieved by a baralime scrubber located in the Engine Room. The inlet air to the scrubber comes directly from the Engine Room and the exit air is distributed equally to all compartments at the rate of 10 cubic feet per minute (CFM)/compartment. Continuous gas analyses for CO_2 levels are taken from the scrubber inlet air. The scrubber is designed to maintain CO_2 levels below 7.6 mm Hg with a baralime replacement interval of 12 hours.

In each compartment, an air conditioning system controls the humidity, odors and temperature. The air flows first to a heat exchanger where the gas is cooled to 55°F and the excess water removed. The cold gas passes over a charcoal bed for odor removal and then through a heater before returning to the compartment via a plenum in the ceiling. In Tank I, containing the Bridge and Crew Quarters, the conditioning loop shares a common inlet located in the Crew Quarters. In the other tank, each recycle loop is separate. In the air distribution system, the only forced circulation between Tank I and II arises from the CO_2 removal system.

The cooling for the air conditioning heat exchangers is supplied by a combination of freon refrigeration and a closed loop water-glycol coolant distribution system. Adequate cooling capacity is available to maintain a relative humidity of 50% in all compartments.

In addition to the air conditioning loops, a fan with a charcoal filter attached is situated over the commode located in the engine room.

The Aeromicrobiology Study[2]

During the first Tektite program, a variety of microbiological and viral studies was conducted. In some, nothing of interest was detected while in others, particularly the swab samples taken from various locations on the human body and the aeromicrobiology study, sufficiently encouraging results were obtained to indicate that further and expanded investigations were desirable. On Tektite I, aeromicrobial samples were obtained in the Wet Lab only. Over the course of the mission two major findings were obtained: 1) there was a progressive takeover of the bacterial population by a marine organism and 2) there was a marked increase in a streptococcus species which occurred two days prior to a respiratory ailment in the crew caused by this organism.

In the wake of these results, an expanded study of the airborne microbial population was proposed for Tektite II.

a. Sampling Protocol

Over the duration of the Tektite II mission, daily samples of airborne micro-organisms will be obtained in two compartments, the Wet Lab and the Crew Quarters. At several periods during this mission a more extensive sampling regime will be instituted to determine the relative distribution of micro-organisms between the four compartments. Each test will last for several days with a number of samples taken per day.

The Andersen sampler to be used in the experiment operates by impinging a flow of microbial laden air onto the surface of nutrient agar plates. The particles stick on striking the damp surface. By a cascade arrangement for the impinging air velocity patterns and the use of a number of agar plates (6), a particle size distribution can be determined. In addition, by using different nutrient media, a classification of the type of micro-organisms present can be obtained. For example, a marine nutrient agar will selectively support the growth of micro-organisms common to a marine environment, thereby allowing a differentiation to be made within the microbial population.

The air flow rate into the sampling device is 1 CFM and, depending upon the microbial concentration, 10 to 30 minutes running time is required to obtain an adequate sample. The criterion for obtaining a representative sample requires that the inlet air be taken from a location which is in the main air flow pattern and is not near major sources of micro-organisms. Since man is by far the most prolific source, his near proximity to the sampling device cannot be tolerated and it must be placed on the floor, bench, etc. where it can run unattended. Dr. Cobet and the author selected tentative sampling locations on the floor near the inlet ducts to the air conditioning system for the Wet Lab and Crew Quarters, on the shelf near the lavatory area in the Engine Room and on the center of the floor in the Bridge.

A microbiology laboratory has been set up in a trailer topside where the agar plates are being prepared daily and transported to the Habitat. Facilities and staff are available for incubation and analysis of the returned samples. Some samples are being preserved for more elaborate analysis in the event that something of unusual interest occurs.

Potential Problem Areas in the EC System

a. The General Electric CO_2 Test

During the ECADS briefing and the subsequent Habitat inspection, both Dr. Cobet and myself were struck by the lack of mixing between the two Habitat tanks arising from the design of the air distribution system, and the possible concentration differences which could occur as a result. According to GE, an unmanned test of the ECADS system in which CO_2 was released only in the Crew Quarters resulted in a negligible CO_2 concentration difference (0.2 mm Hg) between the point of release and the point of removal in the Engine Room. The CO_2 concentration was approximately 5 mm Hg. Since there is no forced air circulation between the two cylindrical tanks except for the supply of 20 CFM of scrubbed air to the Bridge/Crew Quarters and the return of the same volume via the tunnel, GE's reported results did not appear to be correct. An analysis of the test was performed and our preliminary conclusions seem to be confirmed. A straightforward material balance calculation shows that at steady state, the concentration in the Bridge/Crew Quarters should be approximately twice that in the Engine Room. This condition is attained in 5 to 6 hours.

Several possible mechanisms were checked to determine if they could explain the test results. The diffusional component of mass transfer between the two tanks was calculated and turned out to be many orders of magnitude smaller than would be required to account for the results. If forced mixing of the air between tanks (with no net flow) is assumed to be the mechanism, then a flow of air through the tunnel on the order of hundreds of cubic feet per minute would be needed in each direction and this is not likely. The effect of this type of mixing is shown in Fig. 2 where the ratio of CO_2 concentrations between Tank I and II is plotted as a function of the amount of mixing. The derivation of the equations describing the CO_2 concentration levels in the Habitat is contained in the Appendix.

From the analysis performed here, the only conclusion to be drawn is that an inconsistency is present between the air distribution system as described in this paper and the reported data from the GE test. To resolve this discrepancy, the following experimental program is proposed.

A knowledge of the air flow patterns in the tunnel connecting the two tanks is required. A qualitative determination of this pattern can be obtained by visually observing the dispersion patterns that a smoke cloud makes when released in the tunnel. If the predicted pattern is correct, a gentle flow of smoke-laden air at approximately 1 foot per minute should be observed going from Tank I to Tank II. If smoke moves into each tank, then inter-tank mixing is present.

Provided that intermixing is observed, a quantitative evaluation of the extent of this mixing can be obtained by a repetition of the GE CO_2 test with more extensive monitoring facilities. In addition to measuring the CO_2 concentration in the scrubber inlet and in the Crew Quarters, concentration measurements are required in the Bridge and the Wet Lab to verify that good mixing is achieved in each tank, and in the scrubber exit gas to check the efficiency of CO_2 removal. The CO_2 analyses should be accurate to 0.1 mm and the monitors in the different locations should be checked against each other at a common reference CO_2 level to assure internal consistency. Continuous concentration readings are desirable. The test should be conducted using the following protocol:

1. With the scrubber in operation and CO_2 added in the Crew Quarters, establish a steady state CO_2 level of approximately 3 mm Hg in the Crew Quarters. The CO_2 addition required to obtain this level will be approximately 1 liter/minute at ambient conditions. Steady state should be achieved in 6 hours.

2. Increase the CO_2 addition by a factor of two and establish a new steady state.

From the data gathered, the amount of mixing can be determined for each of the two steady states by using the equations developed in the Appendix. The values should be the same. In addition, data taken during the transition between steady states can be compared to a computer solution of the material balance equations derived in the Appendix to verify the extent of intertank mixing.

b. Carbon Monoxide Levels

During the course of checking the ECS and air flow patterns, the problem of CO buildup, an area of concern in spacecraft and other closed environments, was investigated. The primary motivation for looking at CO concentrations was the elevated levels which occurred in the PX-15 Gulf Stream Drift[3] mission and nearly caused its abort. The PX-15 had a completely closed environment with no provision for controlling CO. Activated charcoal (for odor control) and LiOH (for CO_2 control) were ineffective in removing CO, and its accumulation resulted. The time course of this buildup for the PX-15 is shown in Fig. 3[4]. The pattern of CO buildup is quite clear: increasing CO concentrations at ever increasing rates. For the 6-man crew with approximately 400 feet^3/man, the rate of CO generation went from approximately 15 mg/man/day to 30 over the course of the mission, while the actual concentration passed the initial abort level of 25 ppm at day 21 and was almost at the "revised" limit of 50 ppm when the mission ended at day 30.

The ECS situation is somewhat similar on Tektite with the exception of a small continuous flow of makeup air to replace the oxygen consumed by the crew. Excess nitrogen bleeds off through the diving well. This bleed will remove some CO, and depending on its generation rate and the bleed rate, a steady state level of CO will be established in the Habitat. On Tektite I[5], makeup air flow rate to the Habitat was recorded at two-hour intervals and the vast majority of readings was at 16 standard cubic feet per hour (SCFH). Since 5 crewmen will be used on Tektite II versus 4 on Tektite I, the average flow rate should be approximately 20 SCFH. Assuming a P_{O_2} in the Habitat of 180 mm Hg, then the exit gas flow rate needed to remove the excess N_2 entering in the makeup air will be 9 CFH under Habitat conditions of temperature and pressure (25°C and 31.6 psia). At steady state, the concentration of CO is given by

$$C_{CO}\text{ (ppm)} = 0.204 \times \text{Generation Rate (mg/day)}.$$

Carbon monoxide is generated primarily by man in Habitat type environments. Some CO can come from non-metallic materials of construction, but with careful selection, this source can be minimized. Another potential source can be meal preparation if the food is fried, burned, etc., since some pyrolysis will occur resulting in CO formation. In Tektite I, some frying of meat occurred during the latter part of the mission and the crew reportedly[1] made CO measurements and reported informally that the CO levels were satisfactory. What this means is not readily clear since the readings were not recorded.

Reported human carbon monoxide generation rates vary by an order of magnitude. Table I lists several values, their sources, and the steady state CO levels that would result if these rates occurred on Tektite II. Also included is the National Academy of Sciences[6] recommended limit for extended duration exposure. Most of the reported generation rates lie between 10-30 mm/man day except for Gorban and Bogatkov, two Russian investigators whose results appear to be at variance with the data from American experience.

A few CO measurements were taken on Tektite I and are shown in Table II. The reason for the variation in CO levels from 9 ppm on days 13 and 18 to the 20-25 ppm on days 12, 14, 20, 21 is not clear from the record, but they may result from the use of two different measurement techniques. Sampling tubes which rely on a colorimetric test for CO were available in the Habitat and they may have given the higher readings. Two gas bomb samples were taken during the mission for analysis; one was at day 13 and gave a CO reading of 9.3 ppm[1]. The lower readings would appear to come from these two samples.

Further evidence that indicates the use of two analytical techniques arises from the slow rate of change possible in CO levels. The half-time* is approximately 3.5 days so that the recorded changes on May 12, 13, and 14 which were from 25 to 9 and back to 20 ppm are not possible. One explanation for this apparent discrepancy comes from the fact that the gas bomb samples may not have been corrected for the elevated pressure (31.6 psia) at which they were collected. By applying the pressure correction to the two low values, "corrected" readings of 20 ppm result.

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*The half-time is defined as the time required for concentration to reach the mid-point between its initial and final value.

The CO levels on Tektite II will probably range from 15-30 ppm, based on the data presented in Table I. These levels do exceed the NAS recommendations and positive CO control using a catalytic burner would be required to remain below this ceiling. Since the Habitat is already emplaced and the Tektite II mission in progress, such alterations would have a major program impact and, realistically, will probably not be implemented.

The effects of continuous exposure to CO have been recently reviewed by the National Academy of Science(7) and the following pertinent conclusions were drawn:

1. At low concentrations, the principle effect of CO is its reversible reaction with hemoglobin (Hb) to form carboxyhemoglobin (CO Hb), thereby reducing the oxygen transportation capacity of the blood.

2. With no CO in the air, the background CO Hb concentration in the blood is approximately 0.4% of the saturation value. These levels rise to approximately 2.4%, 5% and 9% for 10, 25, 50 ppm CO, respectively, in the atmosphere. The half-time for changes in steady state concentrations in the blood is 4-6 hours (less during exercise).

3. Sensitive tests have shown some impairment in mental performance at quite low levels of CO Hb, less than 2.4%, and that the amount of impairment is proportional to CO Hb concentration. There appears to be a positive correlation between automobile accidents and CO Hb levels. This is possibly due to a decrement in the psychomotor performance of the offending driver.

4. Overt physiological symptoms in healthy individuals usually do not appear at CO Hb concentrations below 10%, (about 50 ppm). The effects of long term continuous exposure at these levels are not known.

SUMMARY

1. The results of the General Electric CO_2 mixing test appear to be inconsistent with the limited mixing possible via the air distribution system. Under the test conditions where all CO_2 was generated in the Crew Quarters, the concentration at the point of release is calculated to be about twice that at the point of CO_2 removal in the Engine Room, instead of the measured ratio of nearly one. Since interpretation of the aeromicrobiology data may be influenced by the mixing patterns present in the Habitat, the difference between the test and predicted values should be resolved. An experimental program is proposed to resolve this discrepancy.

2. Carbon monoxide levels will probably exceed the National Academy of Sciences recommendation by a factor between one and two.

3. Active control of CO concentration using a catalytic burner is presently out of the question. The Habitat is already emplaced and the Tektite II mission is in progress.

4. Since the NAS recommendations are quite conservative, no appreciable physiological effect should be evident in healthy individuals at the anticipated maximum levels of 30 ppm, although some decrement in mental performance may occur. This decrement will probably not be observed in the absence of sensitive measuring techniques.

L. D. Sortland

L. D. Sortland

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Attachments

TABLE I

Tektite II Carbon Monoxide Levels

Reference Source	CO Generation Rate mg/Man day	Tektite II CO Level with 5 men-ppm
General Electric, (1)	9.6	9.8
Conkle, Cited in (8)	11.1	11.3
Sjostrand, Cited in (8)	15-30	15-31
Gorban, Cited in (8)	278.07±160.8	284±163
Bogatkov, Cited in (8)	172.8	177
PX-15, from Fig. 3	15-30	15-31
National Academy of Science, (7)	17.5	17.8
National Academy of Science, (6)		15*

*Recommended Level for 90 day exposure.

TABLE II

CO Measurements on Tektite I

Mission Day	CO Level(ppm)
12	25
13	9
14	20
18	9
20	20
21	20

Mission Duration - 60 days. No recorded measurements during last 39 days.

NOTE: 1. CO_2 SCRUBBER AIR INLET LOCATED IN ENGINE ROOM. THE SCRUBBED GAS IS DISTRIBUTED EQUALLY TO EACH COMPARTMENT (10 cfm/COMPARTMENT).

2. COMPARTMENT VOLUME IS APPROXIMATELY 900 ft^3.

3. OPEN HATCHES CONNECT THE BRIDGES - CREW QUARTERS AND THE ENGINE ROOM - WET LAB.

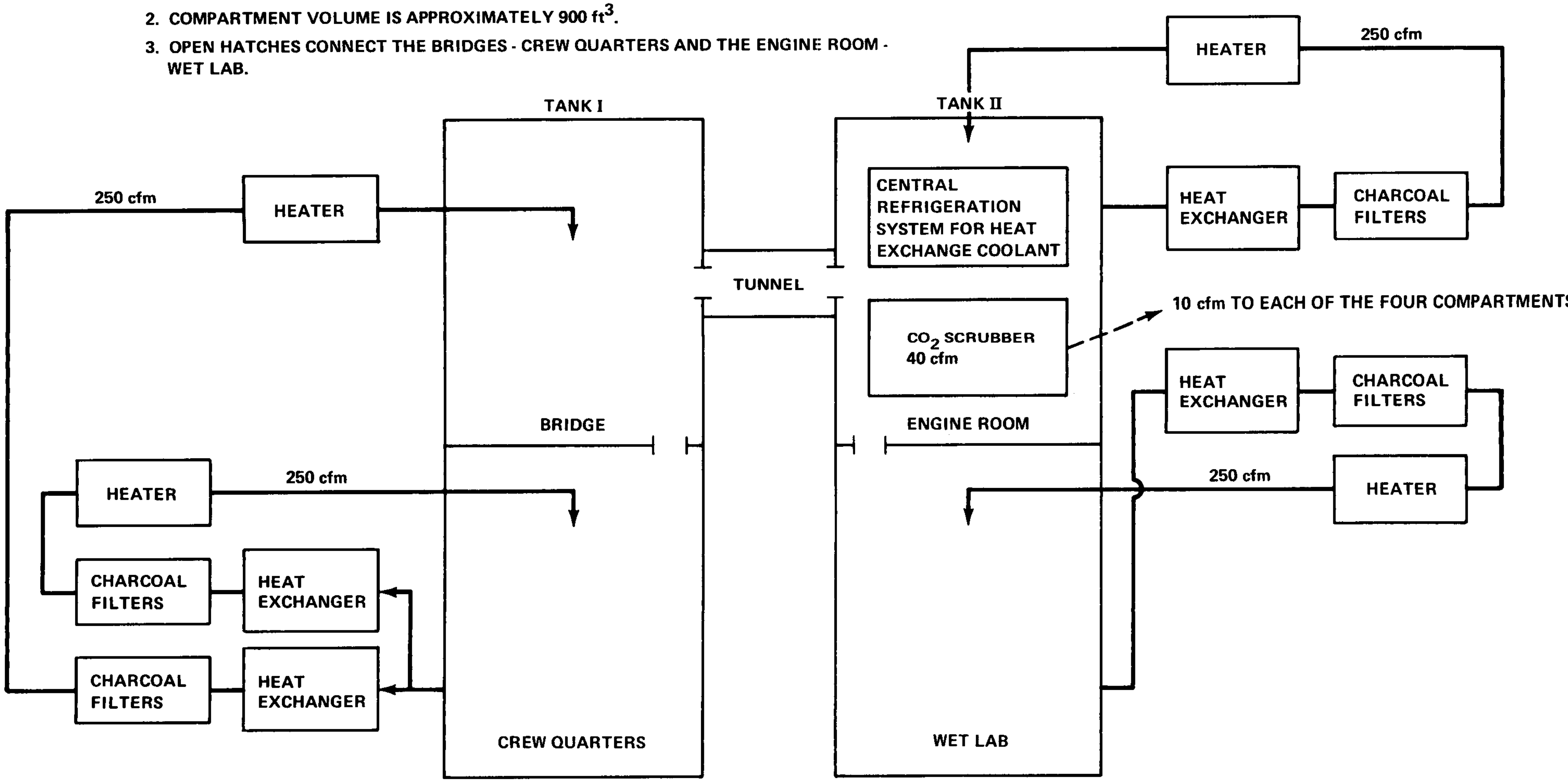

FIGURE 1 - TEKTITE II ENVIRONMENTAL CONTROL AND AIR DISTRIBUTION SYSTEM

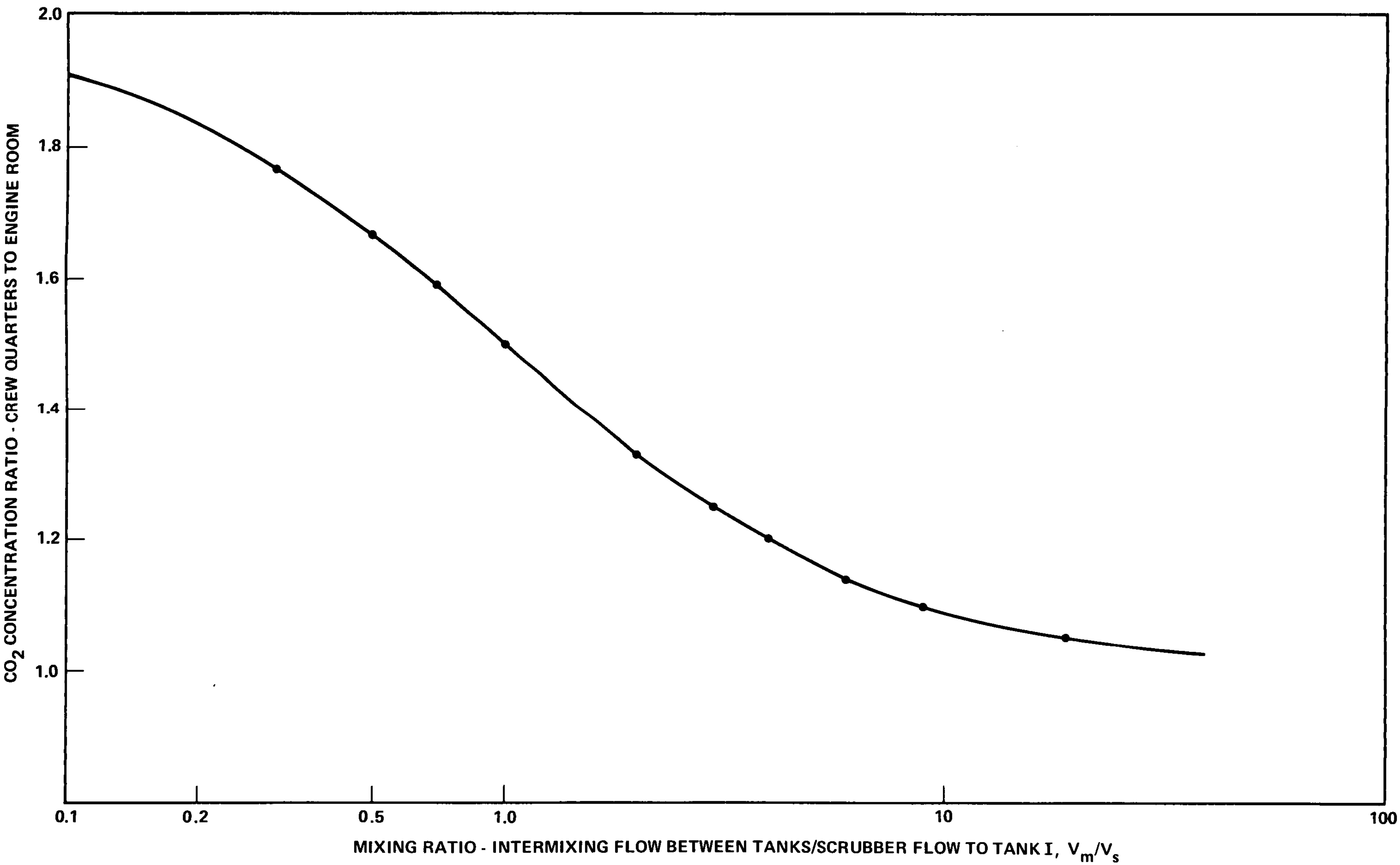

FIGURE 2 - EFFECT OF MIXING ON CO_2 CONCENTRATIONS WITH GENERATION IN CREW QUARTERS AND REMOVAL IN THE ENGINE ROOM

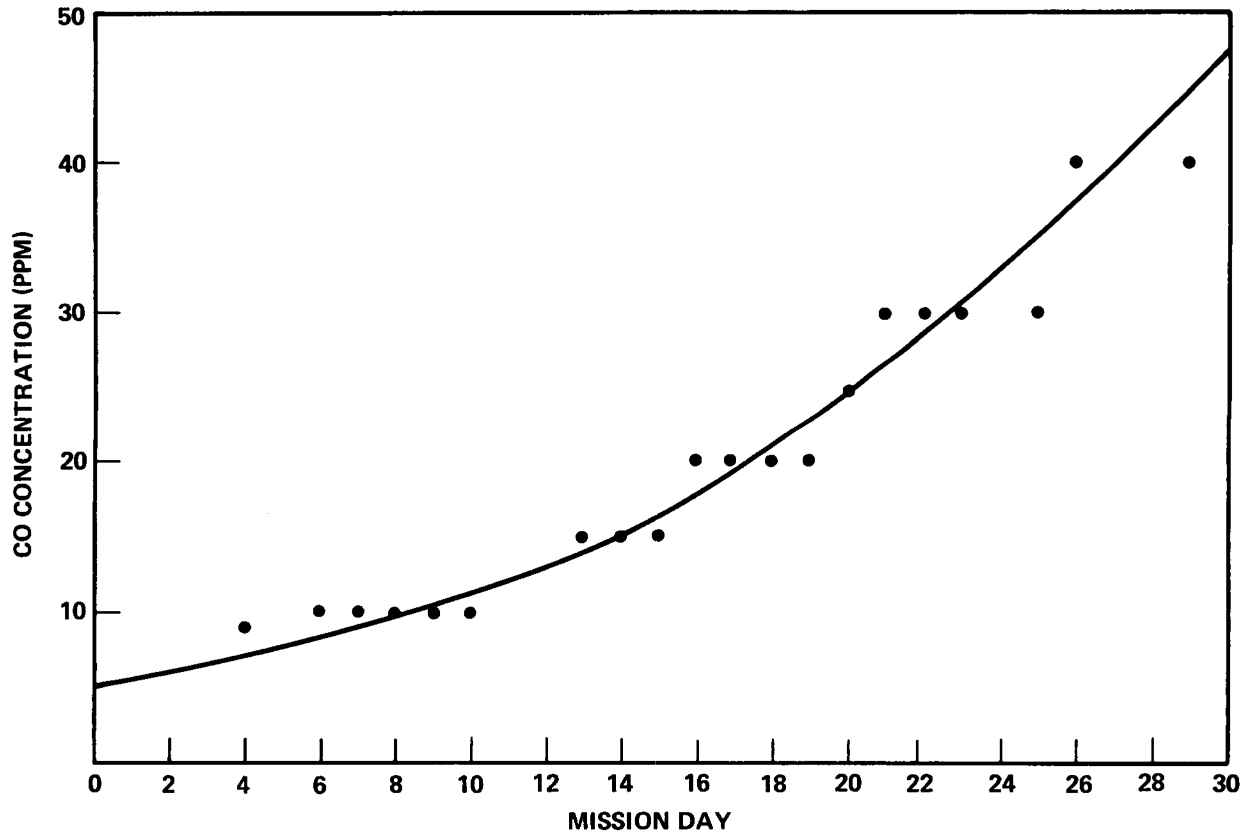

FIGURE 3 - CO CONCENTRATIONS ON THE PX - 15 GULF STREAM DRIFT MISSION

APPENDIX

Using the flow distribution shown in Figure I, the following differential equations describe the CO_2 material balances for Tanks I and II for the G. E. test.

$$V_1 \frac{dC_1}{dt} = K_1 - v_m(C_1 - C_2) - v_s C_1 \tag{1}$$

$$V_2 \frac{dC_2}{dt} = v_s C_1 + v_m(C_1 - C_2) - 2v_s C_2 \tag{2}$$

where:

C = CO_2 concentration

$V_{1,2}$ = volume of Tanks I and II

v_m = intermixing flow rate between Tanks I and II

v_s = net flow from Tank I to Tank II arising from the CO_2 scrubber recirculation.

K_1 = rate of CO_2 release into Tank I

t = time

Assumptions:

1. Each tank behaves as a perfectly stirred vessel.
2. The scrubber removes essentially all of the CO_2 from the gas stream.

At steady state,

$$\frac{dC_1}{dt} = \frac{dC_2}{dt} = 0$$

By adding equations 1 and 2,

$$C_2 = \frac{K_1}{2v_s} \tag{3}$$

From equation 2,

$$\frac{C_1}{C_2} = \frac{2v_s + v_m}{v_s + v_m}$$

$$= \frac{2 + v_m/v_s}{1 + v_m/v_s} \tag{4}$$

In this expression, v_m/v_s is defined as the mixing ratio.

Figure 2 is a graphical representation of equation 4 with C_1/C_2 plotted as a function of v_m/v_s.

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2. Andre Cobet, private communication.
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4. B. A. Gropper, private communication.
5. Derived from Tektite I Data Bank.
6. "Atmospheric Contaminants in Spacecraft", National Academy of Science, 1968.
7. "Effects of Chronic Exposure to Low Levels of Carbon Monoxide on Human Health, Behavior, and Performance", National Academy of Sciences, 1969.
8. D. J. Belz, "Atmospheric Contamination in the AAP Cluster Due to Gaseous Products of Human Metabolism", Bellcomm Technical Memorandum,TM-67-1002-4, November 16, 1967.

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